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Drag reduction by natural polymeric additives in PMDS microchannel: Effect of types of additives

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Abstract. Drag reduction technology was used in medical applications to enhance the blood flow in semi-clogged blood streams which can be an alternative treatment for atherosclerosis. In this present study, natural polymeric drag reducing additives (DRA) was introduced to replace synthetic polymer which has the possibility of bringing side effects to human health. Three different sources, namely okra, aloe vera and hibiscus were utilized to extract the natural polymeric additives which were then tested in custom made microchannel simulating human heart blood vessels. The performance of different types of additives was evaluated using pressure measurements. The maximum drag reduction up to 63.48% is achieved using 300 ppm of hibiscus mucilage at operating pressure of 50 mbar. In this present work, hibiscus showed the best drag reduction performance, giving the highest %FI in most of the cases. This experimental results proved that these natural polymeric additives could be utilized as DRA in enhancing the blood flow in semi-clogged blood streams.

1 Introduction

Atherosclerosis, hardening and narrowing of the arteries, lead to cardiovascular diseases such as heart attacks, strokes, and peripheral vascular disease [1]. Such narrowed arteries can cause turbulence when the blood flows through it which results in increased pressure in the blood vessels and back pressure due to the creation of eddies [2]. The growth of plaques also can significantly reduce the blood flow through vessels. Rupture of plaques can cause blood clots and block the blood flow thus preventing the blood to travel to other parts of the body [3].

With the technologies nowadays, the standard treatment for atherosclerosis is through medication and surgery. However, the drugs [4] do not solve the problem where it only will slow down the progression of atherosclerosis and always come together with side effects. Besides, the degree of success with surgery is limited due to the cardiovascular complication [5] and may also have some side effects after surgery [6]. To solve these problems, several authors reported that a minute amount of long chain polymer can enhance the blood flow which could be an alternative treatment method for chronic coronary artery diseases [7].

This idea was developed from the pioneering work of Toms [8] who had observed the enhancement of flow after adding a minute amount of polymers in pipe [9], which known as drag reduction (DR). Since then, researchers started to gain attention in using natural polymeric drag reducing additives (DRA) to enhance the blood flow. It had been claimed that natural polymeric additives were more resistance to degradation compare to synthetic polymer in the presence of red blood cell [10] where mechanical degradation is a serious drawback in medical applications that will cause the polymer to lose the properties of DRA [11].

Aloe vera as natural polymeric DRA was widely used in researches due to the simplicity in extraction process [12] with minimal toxicity [13]. Polymers extracted from aloe vera was proven to have high performance on DR by improving the survival rate of the animal models of lethal hemorrhagic shock [14, 15]. Besides, it also reduced the number of animal mortality from myocardial ischemia [16]. Although there are some other natural polymeric additives [17-19] are well known for their performance as DRA, there is still limited studies investigating these polymers in enhancing the blood flow.

With the development of microfluidic technology nowadays, researchers started to utilize this technique in as an economical and reliable method for hypothesis testing of the related theoretical phenomena such as DR [20, 21]. *In vitro* microfluidic studies are crucial in investigating the mechanism behind DR in blood flow. Recently, several researchers proposed that, polymeric DRA substantially reduces the near-wall cell-free layer which facilitates the gas transport besides showing excellent DR properties [22, 23].

In this present work, two new natural polymeric additives, namely okra and hibiscus were introduced and investigated their performance on DR comparing with

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aloe vera. Five different concentration (100 to 500 ppm) of these natural polymers were extracted and experimented in two custom-made microchannels that having the real size of human heart vessels to simulate the flow in real human vessels. Note that this work is to test the feasibility of okra and hibiscus as flow enhancer in enhancing the low turbulence intensity flow which analogous to the blood flow using the microfluidic technique.

2 Methodology

2.1 Material

Fresh okra, aloe vera and hibiscus were purchased and cleaned before extraction. Okra and aloe vera were cut into small pieces while hibiscus leaves were picked for the extraction process. These plants were then soaked in 1 liters of ultrapure water separately for 5 hours at room temperature and kept in 4 °C freezer overnight. The extraction process was completed when the plants produced mucilage and turned the liquid into thick, viscous liquid. The solution was then filtered using a sieve to prevent any suspended solids from getting through. Water was evaporated at 40 °C and 90 rpm using vacuum rotary evaporator (model: IKA HB 10) to produce thick mucilage. The mucilage was then ready for dilution to obtain the required concentration.

2.2 Experimental procedure

Fig 1 shows the experimental setup for obtaining experimental data for all mucilage concentrations. In this work, two polydimethylsiloxane (PDMS) microchannels were used where these two microchannels have a real size of human heart vessel with the different clogging part.

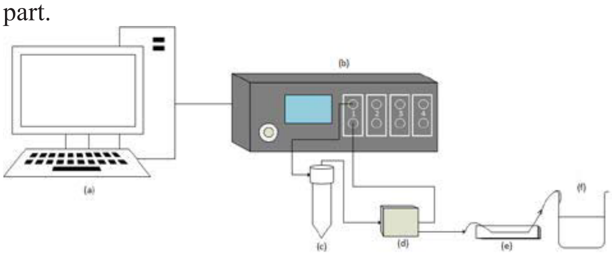

Fig 1. Schematic diagram of experimental setup consisted of (a) computer (b) pressure and vacuum controller (c) reservoir containing solution (d) flow sensor (e) custom made microchannel (f) beaker as storage tank

Fig 2. Custom-made PDMS microchannel that having similar size of human real heart vessel with a semi-clogged part

Mucilage was weighed accordingly and added to deionized water which acts as transported liquid and then being stirred manually to produce five different concentration solution ranging from 100 to 500 ppm.

In this present study, the effect of extracted mucilage on flow enhancement was experimented using an open loop microfluidic system. The operation started by executing commands to pressure and vacuum controller using Elveflow Smart Interface that allowed the operating pressure (50 to 500 mbar) to push the solution out from the reservoir. The flow rate corresponding to the operating pressure was recorded. The steps were repeated for all the five concentration of the three mucilage.

The percentage of flow rate increment (%FI) was then calculated using the formula given as:

$$\%FI = \frac{F_a - F_b}{F_a} \times 100 \qquad \text{(Eq. 1)}$$

where
F_a = Flow rate after the addition of DRA (µL/min)
F_b = Flow rate before the addition of DRA (µL/min)

3 RESULTS AND DISCUSSIONS

3.1. Characterization of mucilage

The extracted mucilage were brought for characterization analysis using Fourier transform-infrared (FTIR). The FTIR spectrum of the sample was recorded using Thermo Scientific Nicolet iS50 FT-IR Spectrometer in the range of 400 – 4000 cm^{-1}, in attenuated reflection mode (ATR).

The composition of components of extracted mucilage were analyzed and tabulated in Table 1. In DR operation, polysaccharides extracted from the natural plant's source are expected to be the main elements to reduce the frictional forces [14, 15]. However, there is no literature reported on the type of sugar that is responsible in DR. Thus, the type of the sugars present in extracted mucilage is the main interest in this study. As shown in Table 1, 19.07% and 20.94% of D-xylulose were detected in okra and aloe vera, respectively. D-xylulose was not detected in hibiscus, yet 27.25% of D-ribulose was detected.

Table 1. Components in extracted mucilage

Components	Composite (%)		
	Okra	Aloe vera	Hibiscus
Water	62.19	65.34	57.79
D-Xylulose	19.07	20.94	-
D-Ribulose	-	-	27.25
D-Pantethine anhydrous	9.63	-	-

3.2 Experimental results

Fig 3 demonstrated the %FI for all three extracted mucilage varying the operating pressure for a different type of additives. It can be clearly seen that %FI was the highest for hibiscus among the three additives for all the cases where the maximum %FI was up to 60%. In this work, okra has the lowest performance in DR giving %FI less than 18%. Aloe vera achieved the medium %FI where the maximum %FI for all the cases did not exceed 55%.

The performance of DR is expected to be affected by the type of additives where the polysaccharide composition in the mucilage plays an important role [24]. In this case, it is expected the composition of the polysaccharides present in the extracted mucilage would directly influence the DR performance. Recall back in Section 3.1, the polysaccharides content in the mucilage were analyzed using FTIR.

In this work, the higher composition of polysaccharides presents in the extracted mucilage resulting in the higher %FI. It can be seen that 27.25% of D-ribulose gives the highest %FI whereas 19.07% of D-xylulose that present in okra mucilage gives the lowest %FI indicating least DR performance. The small difference of the polysaccharides composition, which is less than 10%, in the mucilage gives the significant difference in %FI may be due to the difference type of the polysaccharides existing in mucilage and also the complex interaction with other elements available in the extracted mucilage.

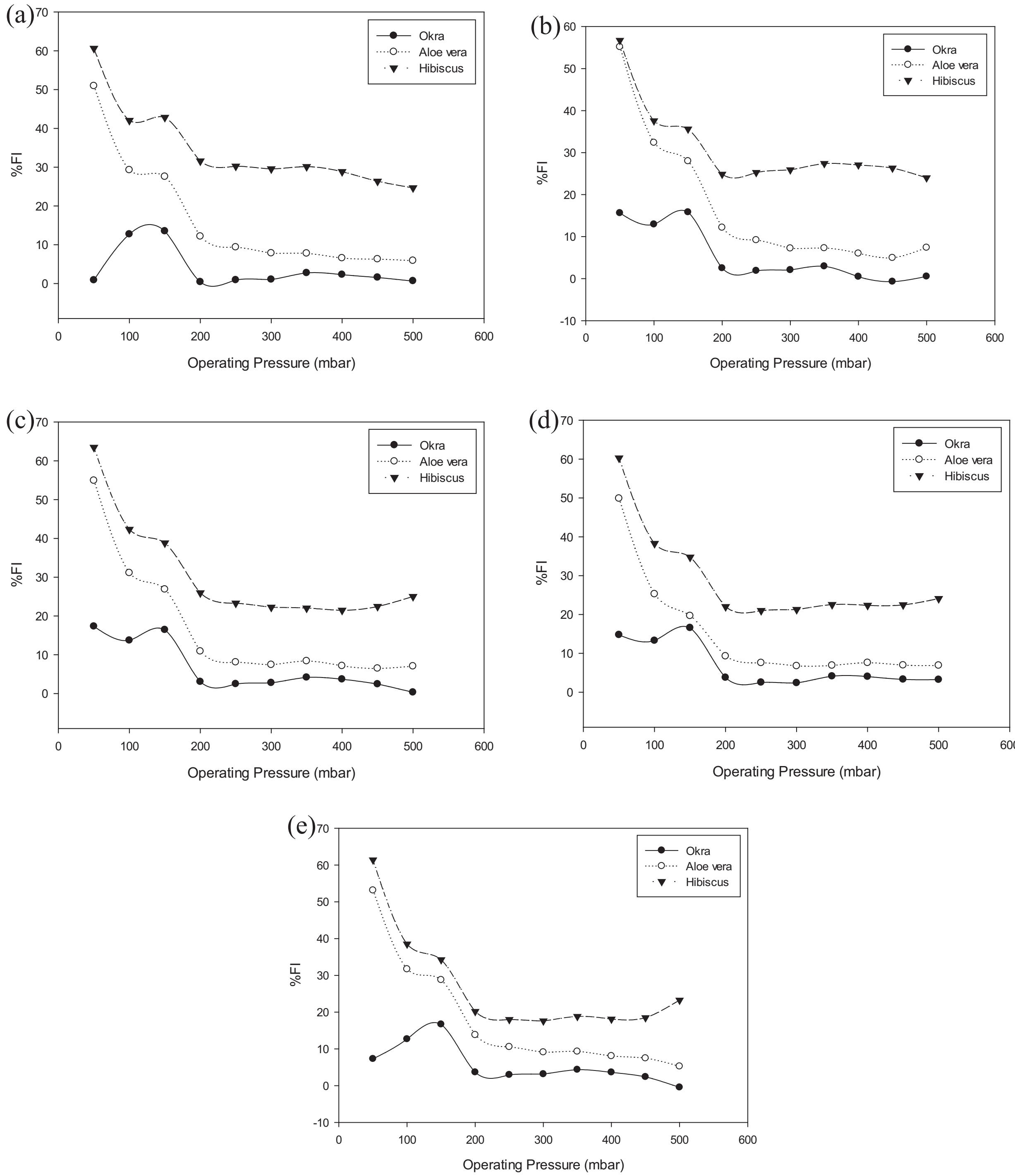

Fig 3. Variation of %FI at various operating pressure for (a) 100 ppm (b) 200 ppm (c) 300 ppm (d) 400 ppm and (e) 500 ppm of three different mucilage in Model 1

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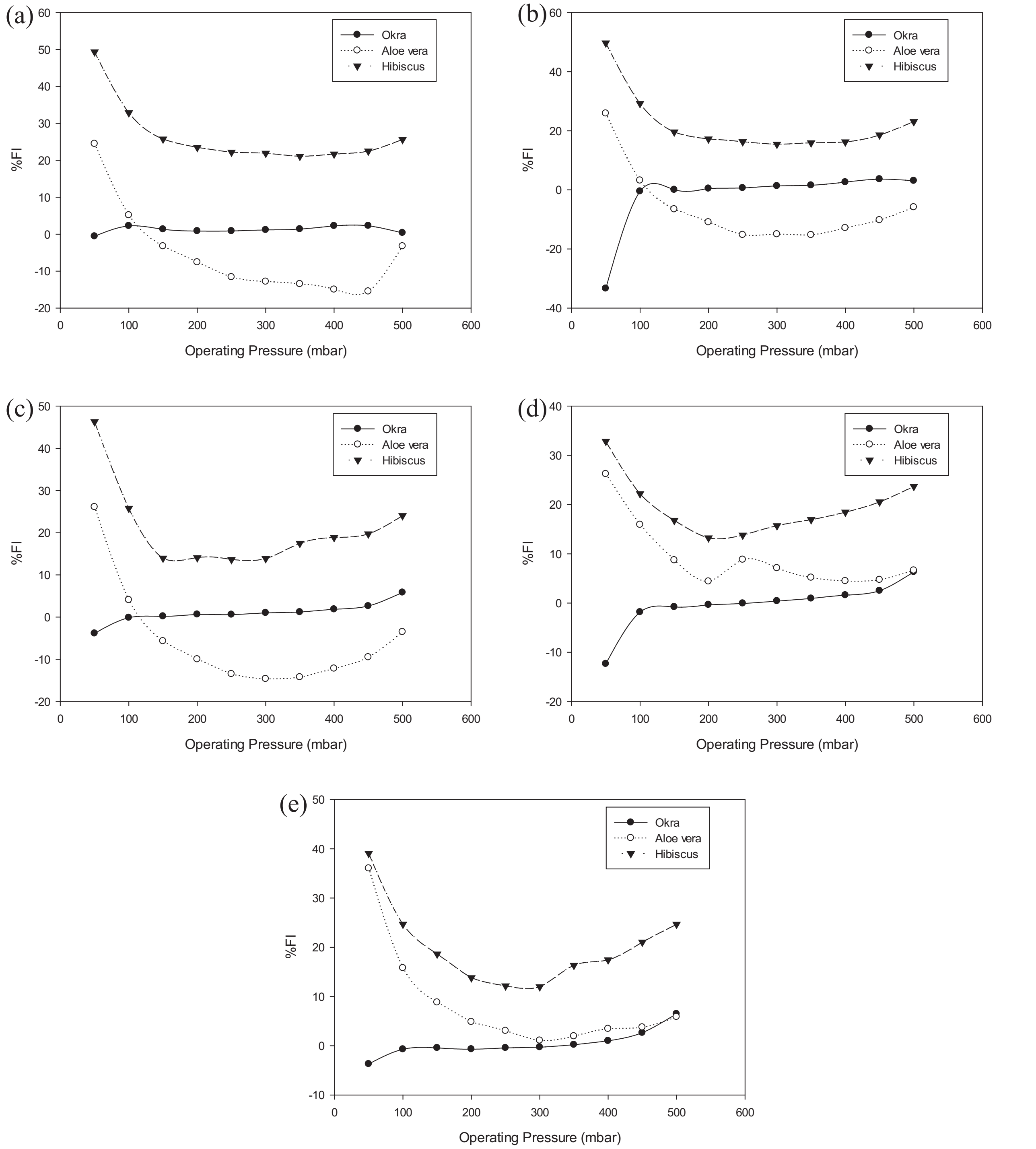

Fig 4. Variation of %FI at various operating pressure for (a) 100 ppm (b) 200 ppm (c) 300 ppm (d) 400 ppm and (e) 500 ppm of three different mucilage in Model 2

Similar phenomena also can be seen in Model 2 as illustrated in Fig 4. Although at a lower concentration, aloe vera did not show much DR effect, the %FI is higher when a higher concentration of aloe vera mucilage was utilized. In this case, okra still showed relatively low %FI with %FI that less than 10%. Hibiscus mucilage showed stable DRA performance where in all the cases, hibiscus still achieved the highest %FI.

The difference in the performance of the extracted mucilage in both Model 1 and Model 2 is expected due to the different clogging location in the design. However, the exact relationship of the location of the clogging area with DR is not reported in this work and other literature.

4 Conclusions

In this present work, the effect of type of natural polymeric additives extracted from okra, aloe vera and hibiscus were investigated using microfluidics technique. The experimental results proved that these natural polymeric additives could be utilized as DRA to enhance the blood flow in semi-clogged blood streams. The composition of the sugar (polysaccharides) group is expected to directly affecting the performance of these mucilage on DR performance. From the results, hibiscus mucilage is the best DRA by achieving the maximum %FI of 63.48% at the concentration of 300 ppm.

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